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DYNAMIC VISUAL ACUITY ASSESSMENT THROUGH VISORS

Alan R. Pinkus

HUMAN EFFECTIVENESS DIRECTORATE
WARFIGHTER INTERFACE DIVISION
WRIGHT-PATTERSON AFB OH 45433-7022

Harry Lee Task

TASK CONSULTING
5513 SNOWBANK CIR
DAYTON OH 45431-2813

Martha A. Hausmann
Maryann H. Barbato

SYTRONICS, INC.
4433 DAYTON-XENIA ROAD
DAYTON OH 45432-1805

Charles D. Goodyear

GENERAL DYNAMICS ADVANCED INFORMATION SERVICES
5200 SPRINGFIELD PIKE
DAYTON OH 45431

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Human Effectiveness Directorate
Warfighter Interface Division
2255 H Street
Wright-Patterson AFB OH 45433-7022

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

//Signed//

BRADFORD P. KENNEY, Lt Col, USAF
Deputy Chief, Warfighter Interface Division
Air Force Research Laboratory

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Alan R. Pinkus* Harry Lee Task ** Martha A. Hausmann ***
Maryann H. Barbato *** Charles D. Goodyear ****

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
**Task Consulting
5513 Snowbank Cir
Dayton OH 45431-2813

***Sytronics, Inc.
4433 Dayton-Xenia Road
Dayton OH 45431

****General Dynamics Advanced Information Services
5200 Springfield Pike
Dayton OH 45431

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*Air Force Research Laboratory
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Air Force Materiel Command
Wright-Patterson AFB OH 45433-7022

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13. ABSTRACT *(Maximum 200 words)*

This study was undertaken to determine the utility of a dynamic visual acuity assessment methodology for examining the effects of looking through a transparent component on visual performance. The different types of transparent components that can be investigated using this methodology include, but are not limited to, night vision goggles, tinted visors, laser eye protection spectacles, and aircraft windscreens. Transparency attributes that can be investigated include transmission coefficient, reflection coefficient, glare, light level, target contrast, target type, resolution, spectral transmission, haze, scratches, and distortion. The visual task may be a target detection or a target recognition type of task, performed with or without search. The methodology used in this study consists of smoothly and continuously decreasing the distance between the observer and a visual test target, until the observer can accurately perform the required visual task. In this study, the observer was required to visually search and detect a circular black dot in a quadrant, while viewing through a tinted visor. The lighting conditions were not at a level for which the tinted visor was intended to be used, so it was expected that the visor would reduce visual acuity instead of aiding visual performance, as it normally would be expected to do. The objective of the study was to determine the 95% reproducibility limit for the methodology. This limit was found to be on the order of 10% to 15%, which is quite good for an assessment of this type that involves human observers performing a visual task over an extended period. The methodology appears to be viable.

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INTRODUCTION

The pilot must, at any given time, be able to see through a combination of cockpit subsystem optical elements. There is large variability among these elements: the transparency (constructed using acrylic, polycarbonate, polyurethane, silicone, and/or glass formed into monolithic or multi-layered structures), coatings (gold, indium-tin-oxide, self-repairing, anti-reflection, and hard coats), visors (solar tinted, yellow, partially-mirrored, laser eye protection (LEP)), night vision goggles (NVGs; F4949 C, D or G, panoramic, hybrid), LEP glasses, and prescription glasses. In addition to these optical elements, ambient lighting conditions (possibly causing reflections, glare, and haze) and cockpit lighting (incandescent, chemsticks, electroluminescent, light-emitting diodes, mixed instrument colors, NVG compatible, instrument-to-instrument luminance imbalances) can potentially degrade the pilots' visual performance. Historically, past investigations have studied a multitude of these effects on visual performance. However, virtually all of these tests were conducted in a static environment. This study utilized the unique capabilities of the Dynamic Visual Assessment Facility (DVAF), where the observer sits in a computer-controlled cart and is moved through three-dimensional space, at a given (simulated) closure rate, toward real targets. Real targets are unique in that they do not have an inherent resolution limit that would be found using a computer generated simulation. Moving the observer toward a stimulus is one step closer to a real-world scenario. The goal of this study was to assess dynamic visual performance methodology as a means of investigating optical and lighting elements effects on visual capability in the cockpit. For this initial study we selected the standard Air Force issue 15% transmissive "solar" visor as a test case. The lighting conditions in the DVAF were far lower than the conditions under which the solar visor would normally be worn, so the results of this study should not be considered indicative of the effects of the solar visor under normal operational conditions. Under the lighting conditions of the DVAF, the 85% reduction in luminance of the ambient light due to the solar visor should result in a loss of visual acuity. The question was whether or not this methodology would reliably verify this predicted loss of visual capability.

METHODOLOGY

Observers: Four in-house observers (two males and two females) ranging in age from 27 to 48, participated in this study. All observers had normal 20/20 Snellen visual acuity or better, with or without optical correction (as necessary). Table 1 lists the observer's visual characteristics.

Table 1. Visual characteristics of observer pool.

Observer #	Eye Color	Prescription
1	Hazel	Eyeglasses
2	Hazel	None
3	Brown	Eyeglasses
4	Brown	None

Equipment: This study was conducted in the Dynamic Visual Assessment Facility (DVAF). DVAF is a 180 ft. long facility that allows the investigation of visual performance under dynamically changing conditions. The facility consists of a computer-controlled cart that runs along a track. The cart moves through a preset speed profile toward a fixed stimulus. The cart computer records the motion profile and other events, such as the distance at which a target is detected, in a file.

The target used in this study was a 3/16 inch diameter, high contrast black dot mounted to a 2 ft square piece of white foam core. This piece of foam core was mounted on a tripod and rotated so that the dot was presented in the center of one of the four quadrants (see Figure 1). A white foam core surround was placed behind the tripod and the piece of foam core containing the target, to provide an evenly illuminated background. This surround had an average luminance of 54.8 cd/m^2 (16 fL). A white foam core surround was also mounted to the cart with an 8.5 inch square aperture. The surround on the cart was adjusted for each observer so that the target remained centered in the opening. The luminance of the cart surround was approximately 49.7 cd/m^2 (14.5 fL).

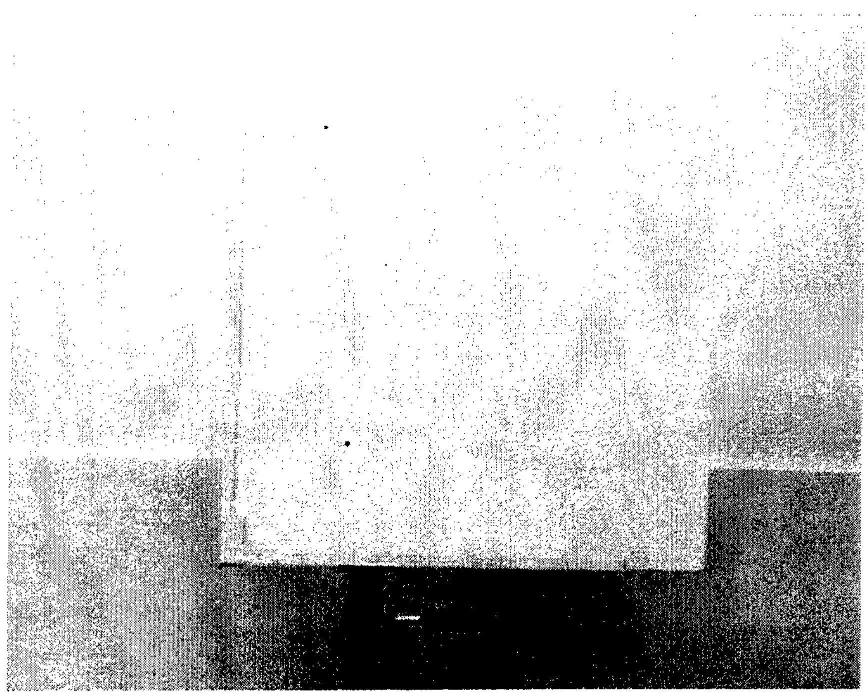

Figure 1. Dot stimulus shown in lower left quadrant.

The observer used a four-button (corresponding to the four quadrants) response box to indicate the quadrant location of the target. The response box triggered the computer to record the target location as well as the distance from the observer to the target.

Figure 2 shows the observer seated in the moving cart holding the four-button response box viewing through the square aperture at the target area. Figure 3 shows the observer's view toward the target from the cart through the square aperture.

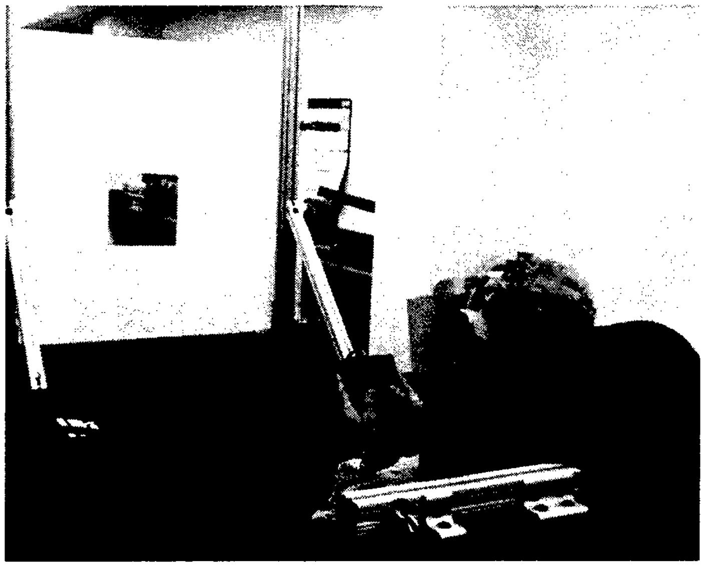

Figure 2. Observer holding response box.

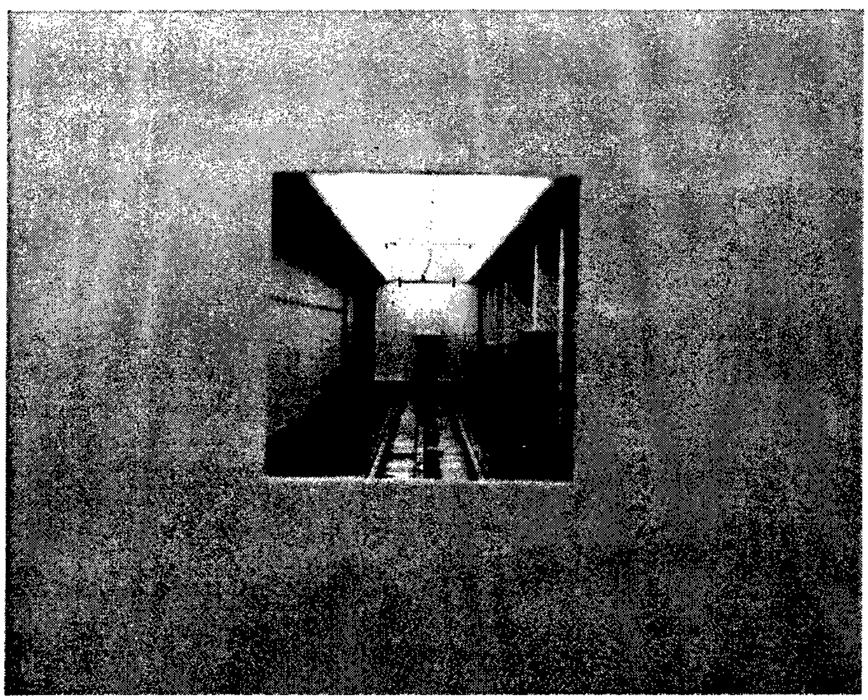

Figure 3. Observer's view of target from starting position.

Conditions: Two conditions were tested in this study; target detection through a 15% transmissive visor and target detection without a visor. The target was randomly presented five times in each of the four quadrants for a total of 20 trials per session. Observers participated in three sessions each for the visor and no-visor conditions for a total of 120 trials per observer.

Procedure: Each observer was briefed on safety procedures of the DVAF, instructions for this study were reviewed and a consent form was signed. The observer was seated in the cart at a starting position where the target was undetectable. They were tasked with detecting the quadrant in which the target was located while the cart moved toward the target. The cart moved slowly at a speed of 32 cm per second. As soon as the target was detected, the observer responded using a four-button response box by pressing the appropriate response button and verbally indicated, to the experimenter, the quadrant that contained the target. They were instructed to respond as quickly and as accurately as possible. The distance at which the observer responded was recorded and the visual angle was calculated. Any missed trials were repeated (5 out of 480 trials). After responding, the cart continued to travel to the end of the track and then automatically returned to the starting position. Each session took approximately 1.5 hours. Data were collected for each observer over six sessions.

RESULTS

The cumulative proportions of visual angle for the 20 trials for each observer and session were determined and a Weibull cumulative distribution (Evans et al., 2000) fit to these proportions. Figures 4a and 4b show these 24 fits. Note that the cumulative proportion of 1.00 for the largest visual angle was changed to 0.99 for modeling to help control the curvature of the Weibull function at the top end. The 50% threshold value is identified in Figures 4a and 4b for the "no visor" and "tinted visor" conditions respectively.

The purpose of this analysis was to determine the reproducibility of the 50% thresholds as shown in Table 2. Reproducibility Limit (RL) is defined as: approximately 95% of all pairs of visual angle thresholds from the same observer and visor condition, generated on different days, should differ in absolute value by less than the RL (ASTM E691-99). The pooled standard deviation (psd) of the three days (i.e., replications) was determined across observers so that RL = 2.77 * psd. Table 3 shows the Reproducibility Limits (RL) for each visor condition. A two-tailed paired t-test showed a significant difference between the visor conditions for the mean 50% threshold ($p = 0.0327$).

Figure 5 depicts the visual angle thresholds (50%) for each observer and visor condition (three replications).

For each pair of thresholds from each observer and visor condition, the absolute difference and relative difference (i.e., absolute difference * 100 / mean) were determined, as shown in Table 4. The cumulative proportions of these values were also modeled using the Weibull cumulative distribution with results shown in Figure 6. The 95th percentiles generated from this modeling are alternatives to the normal theory determination of RL. In each case, a 95th percentile value is generated that represents a worst case difference one could expect for 2 thresholds from the same observer and visor condition, where each threshold was generated on a different day.

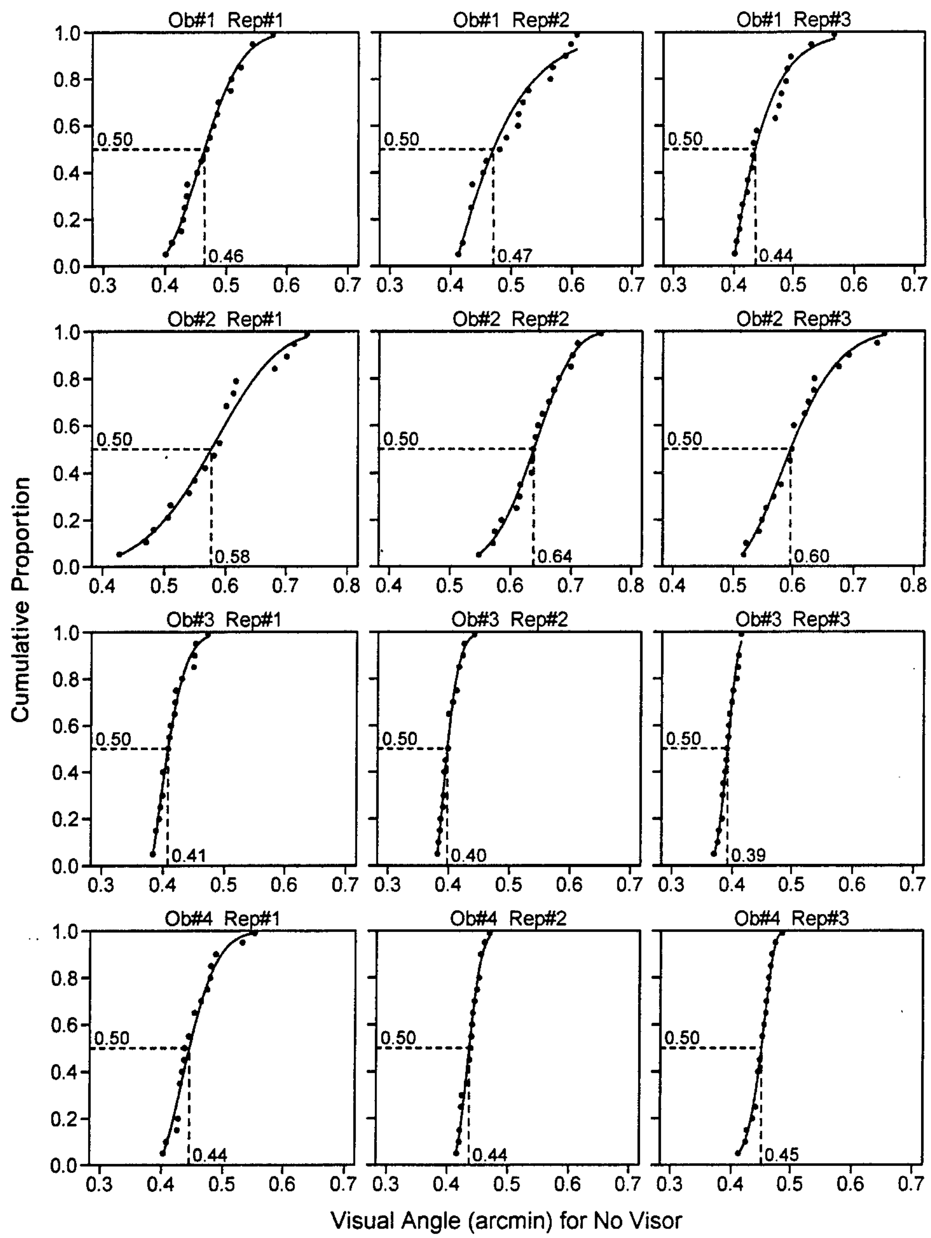

Figure 4a. Fit of sample cumulative proportions of visual angle for *no visor*.

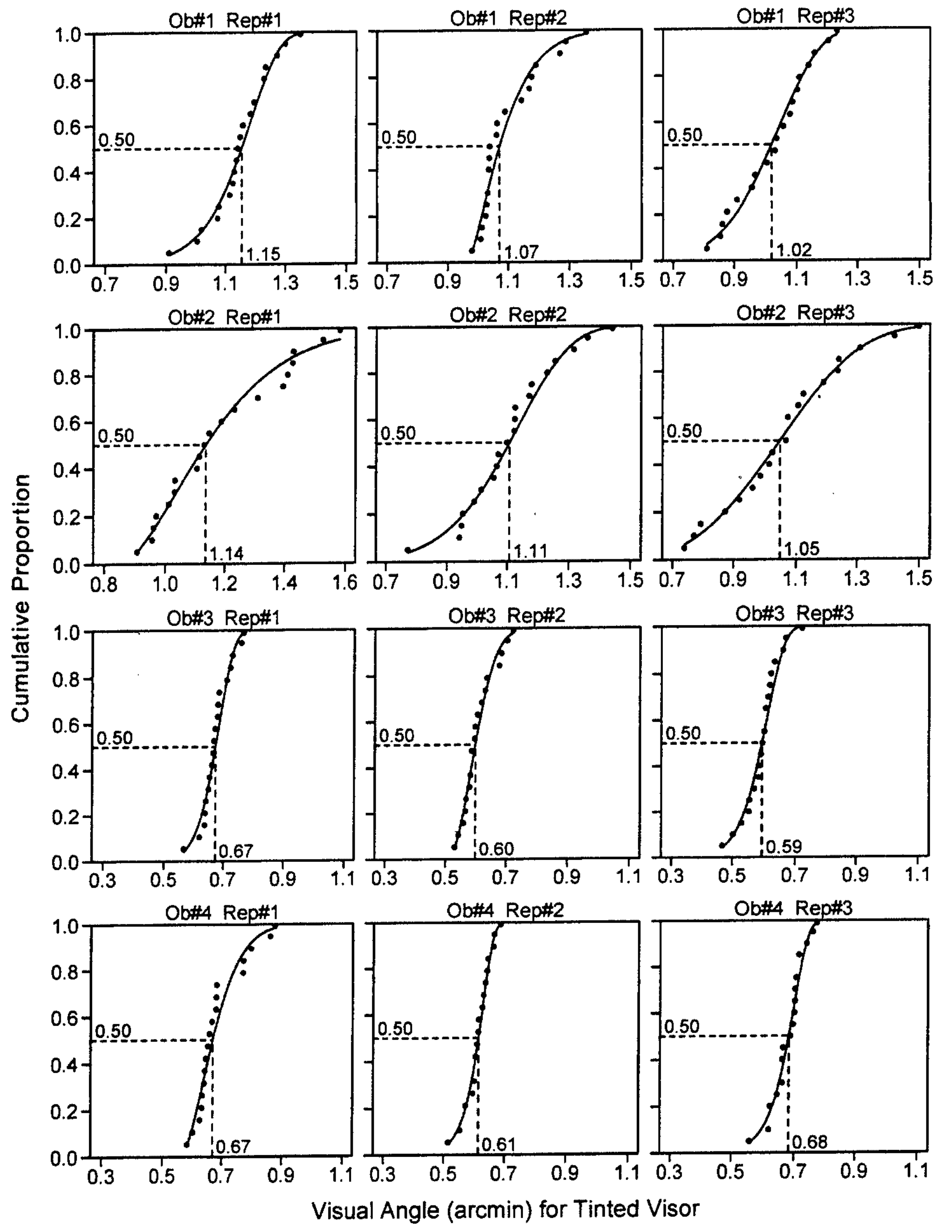

Figure 4b. Fit of sample cumulative proportions of visual angle for *tinted visor*.

Table 2. Fifty percent threshold of visual angle (in minutes of arc) for each visor condition, observer, and replication (i.e., day).

Visor Condition	Observer	Replication 1	2	3	Mean	sd
None	1	0.46	0.47	0.44	0.457	0.015
	2	0.58	0.64	0.60	0.607	0.031
	3	0.41	0.40	0.39	0.400	0.010
	4	0.44	0.44	0.45	0.443	0.006
Tinted	1	1.15	1.07	1.02	1.080	0.066
	2	1.14	1.11	1.05	1.100	0.046
	3	0.67	0.60	0.59	0.620	0.044
	4	0.67	0.61	0.68	0.653	0.038

Table 3. Pooled standard deviation of three replications.

Visor	N	Visual Angle (arcmin) Mean	Pooled sd	RL	RL % of Mean
None	12	0.477	0.018	0.050	10.5
Tinted	12	0.863	0.049	0.136	15.8

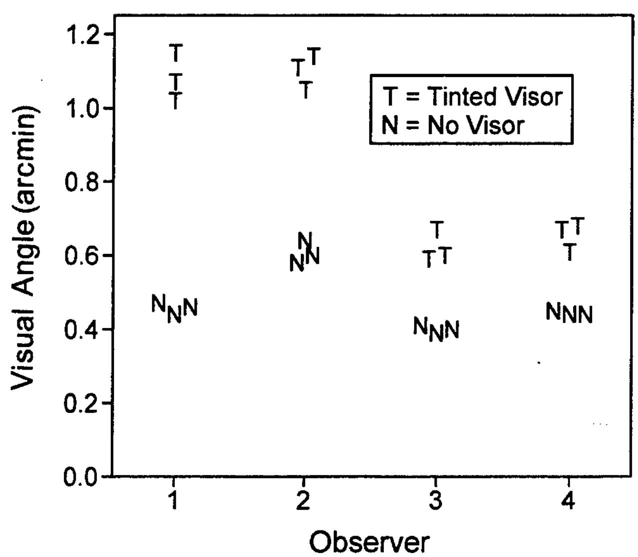

Figure 5. Visual angle thresholds (50%) for each observer and visor condition (three replications).

Table 4. Absolute and relative difference in replication (i.e., day), within observer and visor condition, for visual angle threshold. Data sorted by increasing absolute difference within visor condition. Relative Difference = absolute difference * 100/mean.

Visor Condition	Observer	Threshold Replication 1	2	3	Replication Comparison	Absolute Difference	Cumulative Proportion	Relative Difference
None	4	0.44	0.44	0.45	1 vs. 2	0.00	0.08	0.0
	1	0.46	0.47	0.44	1 vs. 2	0.01		2.2
	3	0.41	0.40	0.39	1 vs. 2	0.01		2.5
	3	0.41	0.40	0.39	2 vs. 3	0.01		2.5
	4	0.44	0.44	0.45	1 vs. 3	0.01		2.2
	4	0.44	0.44	0.45	2 vs. 3	0.01	0.50	2.2
	1	0.46	0.47	0.44	1 vs. 3	0.02		4.4
	2	0.60	0.58	0.64	1 vs. 2	0.02		3.4
	3	0.41	0.40	0.39	1 vs. 3	0.02	0.75	5.0
	1	0.46	0.47	0.44	2 vs. 3	0.03	0.83	6.6
	2	0.60	0.58	0.64	1 vs. 3	0.04	0.92	6.5
	2	0.60	0.58	0.64	2 vs. 3	0.06	1.00	9.8
Tinted	3	0.67	0.60	0.59	2 vs. 3	0.01		1.7
	4	0.67	0.61	0.68	1 vs. 3	0.01	0.17	1.5
	2	1.14	1.11	1.05	1 vs. 2	0.03	0.25	2.7
	1	1.15	1.07	1.02	2 vs. 3	0.05	0.33	4.8
	2	1.14	1.11	1.05	2 vs. 3	0.06		5.6
	4	0.67	0.61	0.68	1 vs. 2	0.06	0.50	9.4
	3	0.67	0.60	0.59	1 vs. 2	0.07		11.0
	4	0.67	0.61	0.68	2 vs. 3	0.07	0.67	10.9
	1	1.15	1.07	1.02	1 vs. 2	0.08		7.2
	3	0.67	0.60	0.59	1 vs. 3	0.08	0.83	12.7
	2	1.14	1.11	1.05	1 vs. 3	0.09	0.92	8.2
	1	1.15	1.07	1.02	1 vs. 3	0.13	1.00	12.0

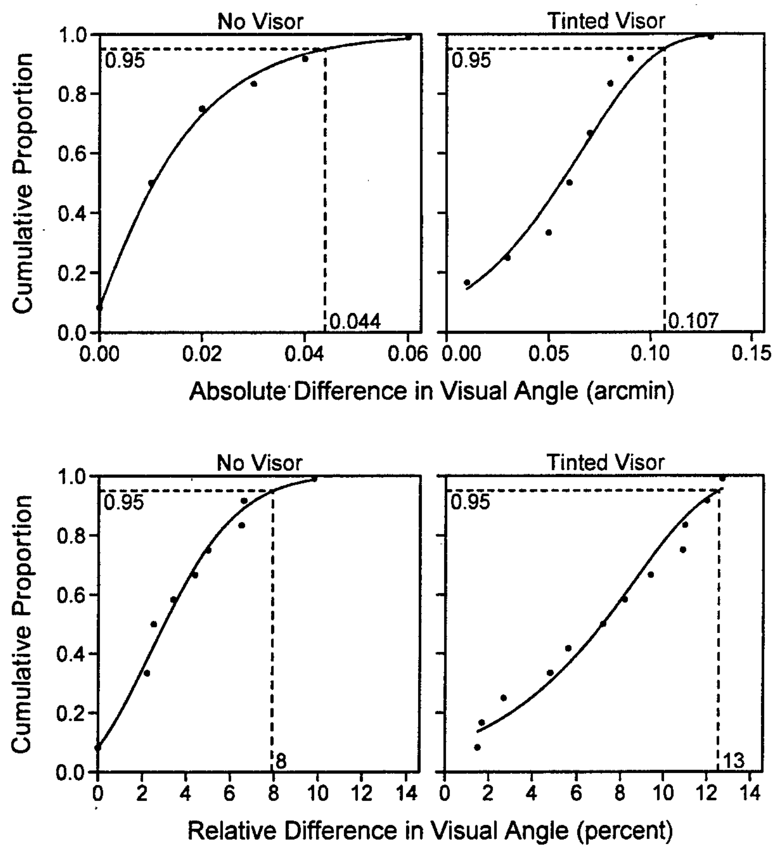

Figure 6. Fit of sample cumulative proportions of absolute difference and relative difference in visual angle. Referenced values are 95th percentiles and are alternatives to RL and RL % of mean, respectively, as shown in Table 3.

DISCUSSION/CONCLUSIONS

As expected, the overall visual acuity of the four observers was worse (larger angular subtense) for the visor condition than for the no-visor condition. Table 3 and Figure 5 show the average angular subtense of the target at the 50% threshold grew from 0.48 arc minutes to 0.86 arc minutes. The average luminance of the target area and the surround for the no-visor condition was approximately 51.4 cd/m^2 (15 fL), 54.8 cd/m^2 (16 fL) around the target area and 49.7 cd/m^2 (14.5 fL) in the surround mounted to the cart. The effective luminance when viewing through the 15% transmissive visor would be 0.15 x 51.4 cd/m^2 or 7.7 cd/m^2 (2.25 fL). According to the literature, (Graham, 1965) the visual acuity for these two luminance values should be about 0.64 arc minutes and 0.81 arc minutes, respectively. It appears our results are in general agreement with the literature.

However, it should be noted that for the visor condition, observers fell into two distinct groups. Observers 1 and 2 showed a larger decrement in visual acuity (increased visual subtended angle of the target) when comparing the visor condition to the no-visor condition. The reproducibility of threshold values for each observer was good, as evidenced in Table 2 and Figure 5, but it is clear that observers 1 and 2 were much more affected by the visor-caused luminance reduction than were observers 3 and 4. We don't have any solid explanation for this but we would like to note that observers 3 and 4 both had brown eyes and observers 1 and 2 both had hazel eyes (van den Berg, et al, 1991; IJspeert, et al, 1990). Regardless, the results shown in Table 2 and Figure 5 demonstrate the existence of individual differences with respect to visual acuity and light levels.

The primary objective of the study, to determine if this dynamic procedure is a viable method to assess the impact of optical/visual components (such as visors) on visual performance, was successfully achieved. Table 2 and Figure 5 show extremely tight groupings of the data for each observer and condition. This tight grouping indicates excellent reproducibility (on the order of 10% to 15%), especially when one considers human observers are involved and thresholds were determined on different days.

The main drawback to this methodology is the relatively large amount of time required to run each observer on each condition. Because of the time-consuming nature of the data collection only one observer /condition could be run in a session and only one session could be run in a morning or afternoon. However, it is also apparent that the procedure, although laborious, produces good reproducibility levels which make it worthwhile. As a result of this study, the cart control software has since been modified to speed the process by immediately ending the run after a response is made instead of continuing to the end of its pre-programmed motion profile. This software modification has resulted in a nominal 50% reduction in the run time, making it a more viable procedure.

Overall, the methodology developed for assessing optical/visual components appears to be successful and could be used in the future for evaluating visors, laser eye protection spectacles, head-up display combiners, aircraft transparencies, ground vehicle windscreens, yellow visors/spectacles, night vision goggles and other optical elements.

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